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Wettability of soil aggregates from cultivated and uncultivated Ustolls and Usterts

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Abstract. Soil organic matter can modify the interaction of clay minerals with water, limiting the rate of water intake of swelling clays and stabilising soil aggregates. Soil structural stability and organic C content usually decrease with cultivation. Faster wetting increases stresses on aggregates and decreases stability. Aggregate wettabilities of prairie soils under 3 different management systems (grassland, no-till, and conventional-till) were compared in the Northern Great Plains of the USA. Six Ustolls and 2 Usterts were selected as replications along the Missouri River. Wettability was measured as water drop penetration time (WDPT) and as rate of water intake under 30 and 300 mm tension. At low tension, aggregates from both cultivated fields and uncultivated grasslands showed similar wettability. Water intake in grass aggregates was attributed to a greater amount of stable pores relative to cultivated aggregates. In cultivated aggregates, slaking created planes of failure that allowed rapid water entry. Differences of wettability between management systems at 300 mm tension (in Ustolls, grasslands had greater wettability than cultivated soils, 0.24 *v.* 0.17 g water/h.g dry soil) and between soil orders (Usterts had longer WDPT than Ustolls, 2.9 *v.* 1.7 s) were explained by both clay and organic C contents. Simple measurements of aggregate wettability may be effectively used for soil quality characterisation. Aggregate wettability is a desirable property for agricultural soils when it is related to stable porosity, as may be found in high organic matter soils (e.g. grasslands). Wettability is excessive when fast aggregate wetting results in aggregate destruction as observed in low organic matter cultivated soils.

Additional keywords: management systems, organic C.

Introduction

Soil wettability is the property of the soil to become wet and is the opposite of soil water repellency. Soil wettability can be measured as the rate of water entry into unsaturated soil. The amount, size, geometry, orientation, and connectivity of soil pores, and the hydrophobicity of pore walls, determine soil wettability or water repellency. Wettability changes with soil pore characteristics and with water potentials during wetting and drying processes. Non-uniform soil wettability in time and space results from differences in proportions and spatial distribution of hydrophilic and hydrophobic surfaces that affect pore stability to wetting. The spatial variability of soil wetting rate is evident in the landscape, in a field, and in a soil profile. Soil wettability includes water entry into inter-aggregate and intra-aggregate pore spaces. Aggregate wettability is one component of soil wettability. Large variations of wettability may be found among aggregates even within homogeneous soil layers and among aggregates of the same size (Doerr *et al*. 1996; Chenu *et al*. 2000). Aggregate wettability depends on intra-aggregate and inter-aggregate flow, which both change as a function of pore and aggregate stability (Tillman *et al*. 1989). Some degree of water repellency can enhance wet aggregate stability (Ellies *et al*. 1995). Relatively slow wetting rates indicate subcritical water repellency (Tillman *et al*. 1989), which may occur when hydrophobic surfaces are not predominant (Hallett *et al*. 2001). Subcritical water repellency may reduce stresses on aggregates by reducing the wetting rate and may result in greater wet aggregate stability and protection from crusting. In contrast, severe water repellency can increase splash erosion, overland flow, and rill formation (Shakesby *et al*. 2000).

Soil management affects soil structure, soil aggregates, soil pores, and their stability, and at the same time affects soil wettability. Soil management can modify the amount and type of soil organic matter. Organic compounds bound to soil

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minerals, organic coatings, and organic debris may be major sources of water repellency (Ma'shum and Farmer 1985; Chenu *et al*. 2000). Hydrophobic particulate organic matter may be responsible for water repellency of the sand-sized soil fraction. Similarly <2-μm-structured particles of organic matter may contribute to lower soil wettability in the clay fraction (Chenu *et al*. 2000). Water repellency may also concentrate in the finest fractions (<0.125 mm in diameter) when separation of aggregates by dry sieving scrapes off hydrophobic coatings and accumulates these coatings in the finest materials (de Jonge *et al*. 1999).

Soils with ≥15–20% clay minerals are not likely to become water-repellent because the structure of water-repellent natural organic compounds is not suitable for attaching to ion-exchanging clay minerals (Farmer 1978). However, both water-repellent and water-soluble organic fractions can decrease the wettability of the soil (Horne and McIntosh 2000). The quality and spatial distribution of organic matter affects the degree and prevalent mechanism of water repellency (Chenu *et al*. 2000). In forestland, management favouring the maintenance of mixed tree stands is favourable to the formation of a thick, water-repellent, humic topsoil compared with single-species sites (Buczko *et al*. 2002).

In prairie soils with dominant smectitic clay minerals, the wettability is affected by changes of porosity and pore characteristics due to the swelling of clay minerals and organic matter during wetting (Tillman *et al*. 1989). Structural stabilisation by organic matter can decrease soil wettability in smectitic soils because slaking is prevented.

Soil slaking is the process of fragmentation that occurs when rapid wetting produces failure of dry, unstable soil aggregates, as a consequence of differential swelling and pressure by entrapped air (Quirk and Panabokke 1962). Incipient failures occur at the boundaries between assemblages of clay particles, predisposing the soil to slaking (Murray and Quirk 1990). Water passes into unstable aggregates quickly through failure planes, causing the breakdown of slaking aggregates (Panabokke and Quirk 1957). Organic matter can prevent aggregate failure by supporting a stable network of continuous pores that can conduct water to all aggregate parts, minimising differential stresses from clay–water interactions (Quirk 1979).

Soil management can modify not only soil organic matter content and type, but also the interaction of soil organic matter with soil minerals and water. As a result, in a study by Ellies *et al*. (1995), wettability appeared more sensitive than organic matter to management changes. In forest, range, or agricultural soils, increased intensity of management appeared to decrease wettability (Ellies *et al*. 1995). In paramos of the northern Andes in Ecuador, intensive grazing strongly decreased soil organic matter content and created a highly water repellent microstructure (Podwojewski *et al*. 2002). Soils with native vegetation cover appeared less wettable and more structurally stable than cultivated soils (Chenu *et al*. 2000). Higher water repellency was measured in the topsoil of grasslands than in tilled corn fields (Sonneveld *et al*. 2003). Plowed soil showed much higher wettability than pasture soil (Hallett *et al*. 2001). In soils where coatings are common, tillage may increase the wettability by abrasion (Tillman *et al*. 1989). Aggregates from soils under no-till management systems were less wettable than plowed treatments (Hallett *et al*. 2001).

The wettability of prairie soils has not been related to soil management practices and soil properties. Therefore, the objective of this study was to determine the effect of soil management systems on soil wettability in agricultural soils of central South Dakota and to relate soil wettability to structural stability, organic C, and clay content. The climate of this region of the northern central Great Plains of the USA has a ustic moisture regime characterised by a wet spring and early summer followed by a dry late summer, autumn, and winter (Soil Survey Staff 1999) and the majority of soils are Ustolls and Usterts. Ustolls are characterised by a thick (>20 cm), dark topsoil and contain smectitic clay, but they are not self-mixing. Ustolls show horizons with distinct properties and do not develop large deep cracks during dry periods of the growing season. Usterts are self-mixing soils containing >35% shrinking and swelling clay. Usterts develop 1–2-cm-wide, >1-m-deep cracks that shut in wet periods and show quite uniform properties throughout the profile (Soil Survey Staff 1999). The following hypotheses were tested on farm field samples of these 2 Soil Orders:

(*1*) wettability is greater in cultivated than in non-cultivated soil aggregates due to slaking;
(*2*) wettability is greater in till than in no-till soil aggregates;
(*3*) wettability is related to soil structural stability, organic C, and clay content.

Materials and methods

Site description and experimental design

Eight locations were selected in the Upper Missouri River Basin. At each site no-till, conventional-till (till), and grasslands (grass) were present in fields in close proximity, on the same soil series, and with similar topography. Ustolls were present at 6 sites and Usterts were present at 2 sites. Seven soil series were considered in the study (Tables 1 and 2). Highmore silt loam was present at two sites. No-till management systems were in place for 6–16 years (average 10 years). Grasslands were typically used for hay or pasture and had never been tilled. Dominant grass species were brome (*Bromus* spp.), wheatgrass (*Agropyrum* spp.), and Kentucky bluegrass (*Poa pratensis* L.). Conventional-till systems generally used chisel plowing as primary tillage and tandem discing as secondary tillage. Depth of tillage varied between 0.07 and 0.20 m. Cropping systems included wheat (*Triticum aestivum* L.), corn (*Zea mays* L.), and soybean [*Glycine max* (L.) Merr.]. The 8 locations were used as replications with each of the 3 management systems compared as treatments.

Four sampling areas with similar soil profiles and landscape positions were selected within each of the individual fields at each

Table 1. Soil series sampled in the study (Soil Survey Staff 1998*b*)

Soil Series	Classification
Lowry	Coarse-silty, mixed, superactive, mesic Typic Haplustoll
Uly	Fine-silty, mixed, superactive, mesic Typic Haplustoll
Reeder	Fine-loamy, mixed, superactive, frigid Typic Argiustoll
Highmore	Fine-silty, mixed, superactive, mesic Typic Argiustoll
Mondamin	Fine, smectitic, frigid Vertic Argiustoll
Millboro	Fine, smectitic, mesic Typic Haplustert
Promise	Very-fine, smectitic, mesic Typic Haplustert

location. Each sampling area was marked using the Differential Global Positioning System (Trimble 1998). A hydraulic 76-mm-diameter soil probe was used to sample and compare soil profiles to 1–1.5 m depth according to standard procedures (Soil Survey Staff 1998*a*).

At each sampling area, soil samples were collected from the topsoil with a spade to 0.20 m depth for measuring wettability of dry aggregates. Samples were air-dried at room temperature, thoroughly mixed, and pooled by treatment at each location. Samples were stored dry at relative humidity (p/p_0) ~0.28 until analysis, without any pre-sieving, grinding, or removing of organic particles.

Water-drop penetration time (WDPT)

The WDPT was used as a measure of wettability (Watson and Letey 1970). Soil aggregates of 10 mm size (5–15 mm) were selected from the 2–25-mm fraction, which had been separated by dry sieving soil samples from the topsoil (0–0.20 m depth). Drops of 100 ± 5 µL of de-ionised water were deposited on the surface of individual soil aggregates, and the time for penetration was recorded (Chenu *et al*. 2000). Measurements were repeated on 100 aggregates per management treatment at each site. Aggregates were considered hydrophilic if <5 s was necessary for water penetration, and hydrophobic if ≥20 s was necessary for water penetration (Bisdom *et al*. 1993; Hudson *et al*. 1994; Doerr 1998). WDPT of aggregates from plots containing >15 g/kg organic C was compared with that of aggregates from plots containing <15 g/kg organic C (Chenu *et al*. 2000).

Wetting rate under tension

Soil aggregates of 10 mm size (5–15 mm) were selected from the 2–25-mm fraction, which had been separated by dry sieving air-dry soil samples from the topsoil (0–0.20 m depth). The wetting rate was measured with an apparatus consisting of Büchner funnels (60 mm diam.) with the sintered glass base connected by a flexible tube to a horizontal graduated glass capillary (Quirk and Panabokke 1962). The system was filled with de-ionised water. Different wetting tensions were obtained by adjusting the vertical distance between the glass capillary tube and the top of the sinter. The largest pores of the glass sinter were of 40–60 µm diameter in order to support a tension of 0.30 m. Ten aggregates (~10 g) were placed on the sinter over a filter paper of high permeability, with the flattest face of each aggregate in contact with the wetting paper. Aggregates were initially air-dry (p/p_0 ~0.28). The rate of wetting was measured by the movement of the meniscus in the graduated capillary, and the amount of water taken up by the aggregates was checked by oven drying. Three repeated-measurements per each management system and site were performed at 2 wetting tensions (0.03 and 0.30 m). Wetting tensions and management systems were organised in a factorial arrangement in a completely randomised block design.

Slaking and other measurements

Slaking measurements were made on 10-mm-diameter air-dry aggregates taken below the surface crust, which was present only in few cultivated plots. Stability to slaking was visually rated from 0 to 6, with a rating of 6 indicating maximum stability (Herrick 1998). In the test, 64 air-dry aggregates per management treatment and site were placed on 2-mm sieves. The sieves were directly immersed in water and the aggregates observed for 5 min. The time (s) for 50% loss of structural integrity was recorded (scores 0 for 0 s, 1 for 0–5 s, 2 for 5–30 s, 3 for >30 s). If after 5 min the structural integrity of the aggregate was maintained, the sieve was lifted and dipped into the water 5 times and the percentage of soil left on the sieve estimated (scores 3 for <10%, 4 for 10–25%, 5 for 25–75%, 6 for 75–100%).

Soil particle size distribution was determined by the pipette method (Gee and Bauder 1986). Soil organic carbon was determined as the difference between total C by dry combustion (Nelson and Sommers 1982) and inorganic C (Wagner *et al*. 1998).

Statistical analyses

Data were analysed using the SYSTAT 9 statistical programme (SPSS 1999). Relationships between measured soil properties were tested by regression analysis. Orthogonal contrasts were made between grass and cultivated treatments and between no-till and till treatments. Additional data analyses were separately done for Ustolls (6 replications) and for Usterts (2 replications). Means of the 2 Soil Orders were compared by *t*-tests.

Results

Wettability measured by the WDPT was not significantly different between management systems (Table 3). All soils had WDPT <5 s and therefore were classified as 'wettable' (Dekker and Ritsema 1995). Soil wetting of aggregates from

Table 2. Clay and sand content and organic C (g/kg) and pH in the top 0–0.20 m of soil in Ustolls (N = 6) and Usterts (N = 2) of central South Dakota (USA)

Probabilities of significant differences in the contrasts between grass and cultivated soils (a) and between no-till and till (b) are reported in the last two columns

Soil Order	Soil property	Grass	No-till	Till	a	b
Ustolls	Organic C	23.7	17.6	14.66	$P < 0.001$	$P \le 0.144$
	Clay	247	253	235	$P \le 0.822$	$P \le 0.238$
	Sand	239	274	311	$P \le 0.152$	$P \le 0.376$
	pH	7.1	7.1	7.0	$P \le 0.642$	$P \le 0.434$
Usterts	Organic C	23.8	20.3	23.5	$P \le 0.412$	$P \le 0.258$
	Clay	551	607	578	$P \le 0.147$	$P \le 0.294$
	Sand	40	36	34	$P \le 0.205$	$P \le 0.656$
	pH	7.9	7.7	8.0	$P \le 0.843$	$P \le 0.074$

Table 3. Water drop penetration time (s) in air-dry aggregates of the topsoil of Ustolls and Usterts under different management systems

The probability of significant differences between cultivated and grass systems and between no-till and till systems is reported in the last two columns (G, grass; NT, no-till; T, till)

Soil Order	Grass	No-till	Till	G *v.* NT&T	NT *v.* T
Ustolls	1.4	1.9	1.7	$P \leq 0.173$	$P \leq 0.668$
Usterts	2.9	3.6	2.4	$P \leq 0.912$	$P \leq 0.157$

samples with organic C content >15 g/kg tended to be slower than samples with organic C content <15 g/kg, but the difference was not statistically significant (2.1 *v.* 1.6 s, $P \leq 0.379$). No significant linear relationship was observed between organic C content and WDPT. On average, the WDPT was significantly shorter in Ustolls than in Usterts (1.7 *v.* 2.9 s, $P \leq 0.017$). In Usterts the rate of clay swelling was likely the dominant factor controlling the rate of wetting. In Usterts, WDPT was linearly and positively related to the clay content ($R^2 = 0.87$, $P < 0.001$). Finer porosity in Usterts than in Ustolls may have contributed to longer wetting time of dry aggregates. Organic C did not explain the differences in WDPT between Soil Orders. The organic C content of Usterts was significantly greater than the organic C of Ustolls only in tilled soils (Eynard 2001).

Further information on soil wetting behaviour was obtained with the tension wetting apparatus. Amounts of water intake measured by following the movement of the meniscus in the capillary (Fig. 1) and by weighing soil aggregates (Table 4) after wetting for 60 min were in good agreement. In all soils, as tension decreased the amount of water intake increased (Fig. 1). Differences between Ustolls and Usterts in water intake after 60 min of wetting were non-significant at a tension of 300 mm, but water intake was significantly higher in Usterts than in Ustolls at 30 mm tension (Table 4). There were no significant interactions between tension and management systems in either Soil Order. At both 30 mm and 300 mm tension, grass aggregates of Ustolls took in more water than cultivated aggregates (0.32 g water/h.g oven-dry soil on average for both tensions in grass *v.* 0.27 in no-till and 0.28 in till, $P \leq 0.014$). At high tension (300 mm) the wetting was slow. Grass aggregates, which had more pores (Eynard 2001), appeared more wettable, because water entered fast and filled the pores <0.1 mm diameter. At low tension (30 mm) aggregate failures favoured water intake in cultivated aggregates so that the amount of water taken in by cultivated soils became closer to that taken in by grass aggregates and the difference in wettability between management systems was smaller than at 300 mm tension. In Usterts, wetting of till and no-till aggregates was not significantly different from wetting of grass aggregates, although at 30 mm tension, till and no-till tended to intake more water than grass. As a result of rapid wetting, aggregates of till and no-till soils may collapse and wet faster, adsorbing more water than grass aggregates (Fig. 1). Greater hydration of soil aggregates in Usterts than

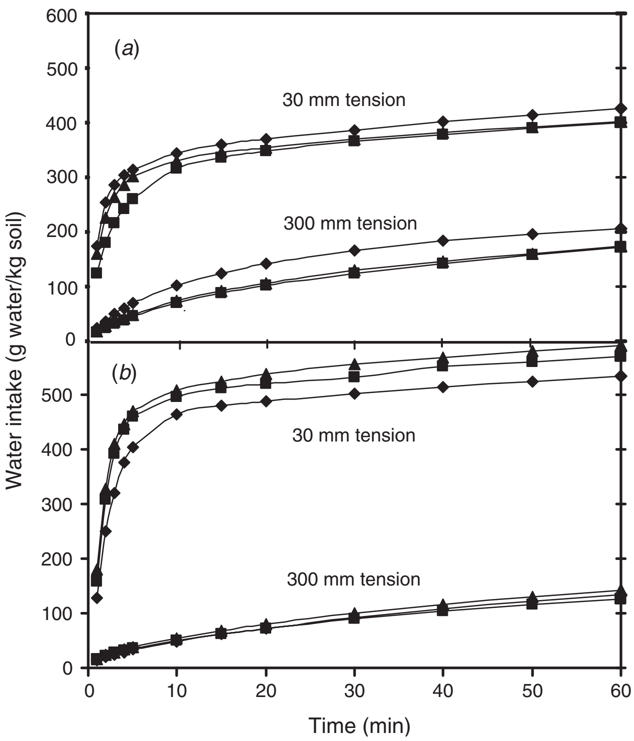

Fig. 1. Water intake at 30 and 300 mm tension for (*a*) Ustolls and (*b*) Usterts. ◆ Grass, ■ no-till, ▲ till.

Table 4. Total water taken in (g water/g oven-dry soil) at a water potential of –300 and –30 mm by air-dry soil aggregates of the topsoil of Ustolls and Usterts under different management systems

The probability of significant differences between Soil Orders is reported in the last two columns

	Ustolls	Usterts	Probability
	300 mm tension		
Grass	0.24	0.18	$P \leq 0.373$
No-till	0.17	0.17	$P \leq 0.955$
Till	0.18	0.18	$P \leq 0.910$
Mean	0.20	0.18	$P \leq 0.480$
	30 mm tension		
Grass	0.40	0.55	$P \leq 0.005$
No-till	0.38	0.58	$P \leq 0.003$
Till	0.38	0.59	$P \leq 0.003$
Mean	0.38	0.58	$P < 0.001$

Table 5. Stability to slaking (rating ranging from 0, unstable, to 6, maximum stability) of air-dry aggregates of the topsoil of Ustolls and Usterts under different management systems

The probability of significant differences between cultivated and grass systems and between no-till and till systems is reported in the last 2 columns (G, grass; NT, no-till; T, till)

Soil Order	Grass	No-till	Till	G *v.* NT&T	NT *v.* T
Ustolls	5.9	5.5	4.7	$P \leq 0.029$	$P \leq 0.038$
Usterts	5.8	4.6	4.9	$P \leq 0.135$	$P \leq 0.588$

Ustolls can be related to the higher swelling-clay content in Usterts than in Ustolls (58 *v.* 25% clay, $P < 0.001$).

Slaking stability was greater in grass soils than in cultivated soils (5.9 *v.* 5.0 $P \leq 0.004$). When the Soil Orders were separately analysed (Table 5), lack of significance of differences in Usterts was probably due to the limited number of replications (2). The stability to slaking in no-till was greater than in till for Ustolls. About 40% of the variability in aggregate stability to slaking was explained by the soil organic C content in both Usterts and Ustolls (Fig. 2). Clay content and aggregate slaking did not appear linearly related in either Soil Order.

Neither clay content nor organic C content appeared related to the water intake of soil aggregates wetted at 300 mm tension. In contrast, clay content explained > 90% of the water intake at 30 mm tension. The linear relationship between clay content and water intake at 30 mm tension was significant in both soil orders (Fig. 3). Furthermore, in tilled soils, fast wetting at 30 mm tension was linearly related to soil organic C content in the aggregates (R^2 = 0.63, $P \leq 0.012$) (Fig. 4). In no-till and grass soils this relationship was non-significant, similar to the relationship between wet aggregate stability and soil organic C, which was significant only in tilled soils ($P \leq 0.002$), where organic C explained 83% of the variation in aggregate stability (Eynard 2001).

Discussion

In Australian Haploxeralfs the wettability of virgin grassland soils at high tension was similar to that of cultivated soils, whereas at low water tension, aggregate breakdown of slaked cultivated aggregates favoured fast water intake in cultivated soils (Quirk and Panabokke 1962). The results on Usterts and Ustolls of our study were complicated by the dominance of smectitic clays, and by significantly greater organic matter contents, porosity, and pore sizes in Ustolls under grass relative to cultivated Ustolls (Eynard 2001).

Organic matter can affect soil wettability by 3 mechanisms. First, hydrophilic organic compounds may decrease the wettability by buffering the soil against water potential fluctuations. Hydrophilic polysaccharides can decrease soil wettability by decreasing the rehydration rate (Chenu 1993; Hallett and Young 1999; Czarnes *et al.* 2000). Second, organic matter can increase the hydrophobic surface. Third, organic matter can stabilise soil pores by holding particles together against external stresses (Panabokke and Quirk 1957; Quirk and Williams 1974). Differences in organic matter distribution and composition, as previously indicated for Australian Haploxeralfs with similar porosity and pore size distribution (Quirk 1979), are likely to have contributed to different stability and wettability measured in this study in different management systems and soil orders in the northern Great Plains. In Hapludands of Chile under forest, abundant hydrophobic organic components seemed key factors in the wetting behaviour of the soil. In Hapludands under grass and crop management the wettability appeared controlled by both the

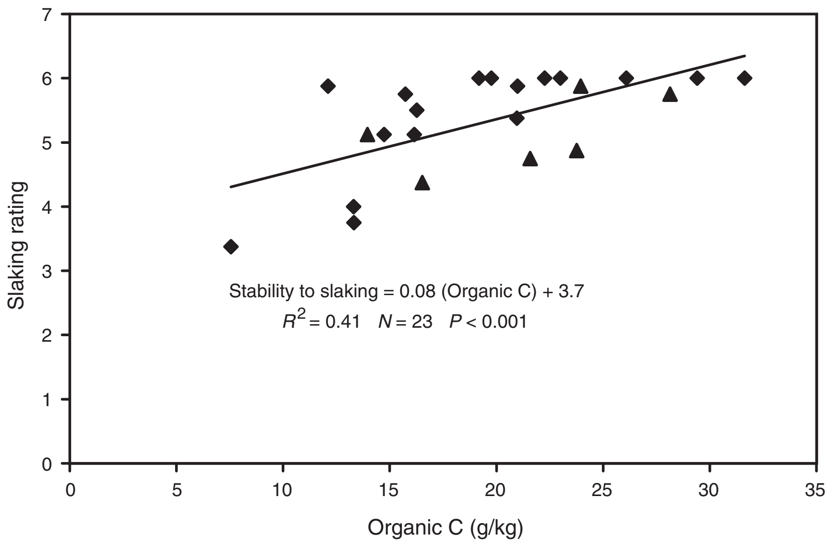

Fig. 2. Relationship between organic carbon and stability to slaking in Ustolls (◆) and Usterts (▲).

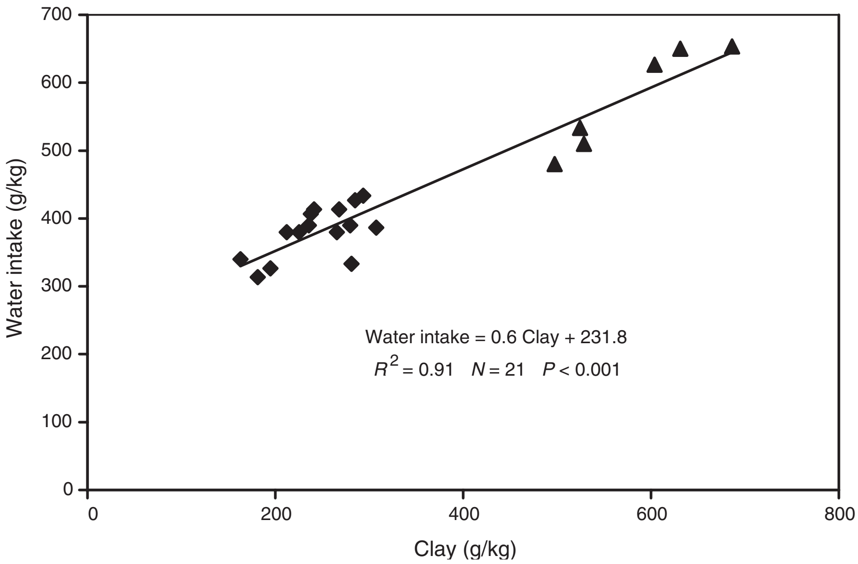

Fig. 3. Relationship between clay content and water intake at 30 mm tension after 1 h in Ustolls (◆) and Usterts (▲).

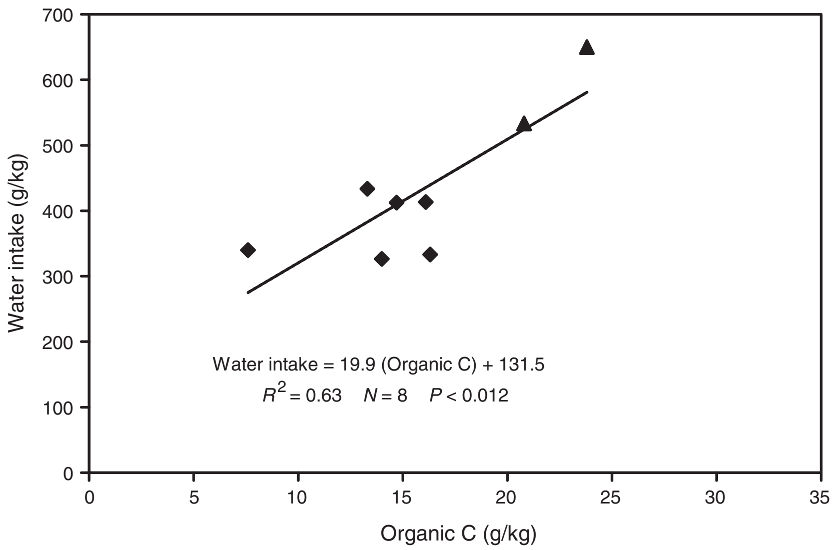

Fig. 4. Relationship between organic C and water intake at 30 mm tension after 1 h in tilled Ustolls (◆) and Usterts (▲).

hydrophobicity of organic matter and the porosity of the soil (Ellies *et al.* 1995).

Porosity, pore conductivity to water, and pore stability are the main factors determining the wettability in soils where hydrophobic surfaces are present in limited amounts. In our experiment, both original porosity and variations of porosity consequent to swelling and slaking can assist in explaining the wetting properties of Ustolls and Usterts in the northern Great Plains. Different pore amounts and characteristics in different Soil Orders and management systems may hide clear relationships between wettability, slaking, organic C, and clay in this study. A positive feedback loop mechanism occurs between wettability and slaking. Rapid soil wetting favours slaking, which further increases soil aggregate wettability. In the case of Ustolls and Usterts that contain smectitic clays, mechanisms of air entrapment (compression of occluded air in capillary pores) and differential swelling act simultaneously, since aggregate destruction by air pressure increases the surface accessible to the swelling action of water (Grant and Dexter 1990). On the other hand, pore occlusion by clay swelling favours air entrapment (Panabokke and Quirk 1957). Stresses from rapid wetting are enhanced by the rapid release of heat of wetting and by the mechanical action of moving water (Chan and Mullins

1994). A result of slaking is that a greater amount of water is retained by the soil in the open network of clay domains compared with water held between aggregates bound together by organic matter (Quirk and Panabokke 1962). Slaking can explain why higher water content is retained by the soil when the wetting rate is faster (Chan and Mullins 1994). The process of aggregate weakening at lower wetting rates than for slaking is described as mellowing (Grant and Dexter 1990). Mellowing of aggregates occurred during the wetting at 30 mm water tension in this study.

Fragments from slaked soil aggregates include smaller aggregates and individual particles. As the wetting rate and the forces causing slaking increase, the size of the fragments produced tends to decrease (Chan and Mullins 1994; Ellies *et al*. 1995). In our study we did not measure the meanweight diameter (MWD) of slaked aggregates, but elsewhere WDPT and MWD of slaked aggregates were shown to be significantly related (Chenu *et al*. 2000). Low wettability was related to minimum variability of MWD during wet sieving (Ellies *et al*. 1995).

Adsorbed polysaccharide networks on soil minerals have mechanical properties that can significantly withstand pressures created in the aggregates by rapid wetting (Czarnes *et al*. 2000; Ferruzzi *et al*. 2000). Loose networks of polysaccharides can provide reinforcement against slaking, allowing air to escape through the largest pores without disrupting the aggregates. Air release through the largest pores can also slow down water entry through these pores (Ferruzzi *et al*. 2000). Analyses of soil polysaccharide contents could provide useful information for interpreting soil wettability and the relationship between wettability, pore stability, and organic C in Ustolls and Usterts.

Conclusions

Cultivation of the prairie changed soil wettability, with different effects depending on Soil Order. All measurements of wettability in our study showed a decline of wettability in cultivated Ustolls relative to the never-tilled grassland Ustolls. Usterts showed a longer water-drop penetration time and a greater water intake than Ustolls at 30 mm tension. In our study, linear relationships were found between soil wettability and clay and/or organic C content in both Ustolls and Usterts. Soil wettability and soil structural stability to water are closely related, because wettability results from surface hydrophobicity, initial porosity, and pore stability to water entry. Slaking tests are a measure of aggregate and pore stability to water entry. In our study, stability to slaking was lower in cultivated soils than in grass. Stability to slaking was linearly related to organic C content in both Ustolls and Usterts.

Slaking may help to explain the wettability of soils in this study. Faster wetting, i.e. higher wettability, increases stresses on aggregates and decreases stability. Failure of aggregates consequent to fast wetting increases the wetting rate because water can enter faster through aggregate failures. Increased wettability may result from aggregate breakdown. Organic matter associated with clay minerals can modify the interaction of clay minerals with water, limiting the rate of water intake of swelling clays. At high water tension, when aggregate failure is limited and aggregates may only start mellowing, greater stable porosity can increase the wettability of aggregates with higher stability relative to weaker, less porous aggregates. However, when aggregates are subjected to fast wetting, differences between aggregates with different stability and wettability may disappear. The high water intake due to greater amount of stable pores conductive to water in grass may have been balanced by water entry in cultivated aggregates through the planes of failure breaking down the aggregates. Consequently, at low tension the wettabilities of air-dry aggregates from cultivated fields and uncultivated grasslands were found to be similar in this study. Clay and organic C contents both contributed to differences between Soil Orders and management systems in wetting properties of cultivated and non-cultivated Ustolls and Usterts in the northern Great Plains of the USA. Differences in aggregate wettability between high (300 mm) and low (30 mm) tension support the finding of Quirk and Panabokke (1962) that incipient failure can take place even in the presence of a suction. This is different from directly immersing dry aggregates in water. Above a particular rate of wetting, failure takes place. Like other measurements of aggregate stability, aggregate wettability relates to rainfall intensity. When rainfall intensity exceeds the actual rate for incipient failure, aggregates fail and the inter-aggregate porosity is lost. Aggregate wettability is a desirable property for agricultural soils when it is related to stable porosity, as may be found in grasslands. Wettability is excessive when fast aggregate wetting results in aggregate destruction, as may be observed in cultivated soils.

The measurement of wettability as done in this study does not require any expensive equipment and may be an important parameter to be included in the definition of soil quality.

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